

A META-ANALYSIS OF APERIODIC NOISE STRESS ON HUMAN PERFORMANCE

B.M. Saxton*, J.M. Ross, A. Braczyk, G.E. Conway, J.L. Szalma, and P.A. Hancock
University of Central Florida
Orlando, Florida, 32816

ABSTRACT

Aperiodic noise, also known as intermittent noise, is a pervasive and influential source of stress across military environments, and can be defined by the changes in its intensity over a given period of time (therefore containing 'gaps' between louder phases of the noise). With examples ranging from the discharge of weapons to vehicle and machinery movements, then it is intuitive to recognize that this common form of noise may constitute a risk to Soldier performance across a range of tasks (i.e., as measured by speed and accuracy metrics). In order to quantify these effects, a meta-analytic evaluation of aperiodic noise effects on performance was undertaken. The results indicate that a general effect of aperiodic noise is to exert a negative influence on performance; however this effect is contingent upon the type of tasks and performance measures used. These results can be used to inform decisions concerning when noise should be mitigated or even alternatively exploited in military settings.

1. INTRODUCTION

Humans are constantly exposed to environmental stressors, one of which is noise stress. Noise stress includes, *"all disturbances, annoying and hazardous sounds influencing the hearing organ and other senses of the human body"* (Engel, Augustnska, Koton, & Kacmarska, 2006, pp 1826). Though many researchers have examined the relationship between noise stress and human performance, the results have been mixed regarding the direction and size of the effect. In order to potentially summarize this confusing situation, a quantitative meta-analysis was preformed to obtain a global effect-size to determine whether noise stress facilitates or debilitates human performance.

2. METHODS

A sampling of the noise stress and human performance literature was conducted and 425 reports were acquired for the meta-analysis. The articles were

obtained through literary search engines using PsychINFO, MEDLINE, and Dissertation Abstracts International Databases. Using these literary search engines the primary search terms "noise" and "speech" were combined with the following secondary search terms: "memory", "decision making", "problem solving", "attention", "vigilance", "tracking", "marksmanship"/"shooting", "fine motor", and "gross motor."

In order to ensure meaningful combination of results each of the research papers was evaluated based on five inclusion criteria. The first criterion was that the paper had to contain an empirical study examining intermittent noise stress as an independent variable. The second criterion was that the experiment must compare a control (lower dB) and experimental (higher dB) conditions. Third, each study must contain a dependent variable that measured human performance. Fourth, the sample within the experiment must be healthy adult participants, and finally, each study had to present enough information to obtain effect size statistics. Out of the original 425 acquired articles, 107 separate effect sizes were calculated, which resulted in a 25% inclusion rate.

Performance types were categorized using the taxonomy used in the US Army's Improved Performance Research Integration Tool (IMPRINT) performance modeling tool. Task types were initially separated into in four higher-level categories, according to main type of demand made on the human performer by the task at hand. Performance was therefore categorized as perceptual, cognitive, motor, or communication tasks. These task types were then further divided into nine lower level categories, in order to recognize the differential demands within each of the higher order categories. The nine categories were therefore: perceptual (visual recognition/discrimination), cognitive (numerical analysis), cognitive (information processing/problem solving), motor (fine motor discrete), motor (fine motor continuous), motor (gross motor light), motor (gross motor heavy), communication (reading & writing), and communication (oral). Examples of these categories are as given below, to aid clarity.

Perceptual (visual recognition/discrimination) tasks are those that require a visual identification of a target

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(e.g., seeing a moving target in the distance). Cognitive (numerical analysis) tasks are those that require the performer to carry out mental arithmetic calculations while cognitive (information processing/problem solving) tasks are those that require the mental processing of information for the purposes of forming a final conclusion (e.g., deciding the best firing location). Motor (fine motor discrete) tasks require little effort in performing distinct motor actions within a particular sequence (i.e. pressing a series of buttons), whereas a fine motor continuous task requires a participant to maintain an uninterrupted series of movement actions within a certain level of performance (e.g., tracking task using a joystick or driving a vehicle). Gross motor (heavy) tasks require a large physical effort to perform the required action (e.g., moving a large object). Gross motor (light) tasks require movements featuring multiple body parts, though with little physical effort (e.g., cleaning a weapon). A communication (reading & writing) task requires reading and/writing text (e.g., a checklist), and communication (oral) tasks require the participant to listen or talk to another person (e.g., receiving an order).

Separate categorizations were made according to the type of performance measure used, in terms of whether the tasks emphasized *speed* or *accuracy* of the response. As meta analyses allow a hierarchical approach, it was also possible to assess the degree to which effects on one level (e.g., the task type) were moderated by effects on another level (e.g., whether speed or accuracy was emphasized as a response criterion). Though these hierarchical analyses allow the opportunity to examine specific combinations of factors, it must be recognized that the more specific the data are, the less data there is. Hence, some moderator analyses contain a limited or no number of studies.

The data were analyzed using calculations of effect size. As few papers provided effect sizes in their results, effects were computed using several equations, depending on the data provided. Equation 1 was used to calculate effect sizes when means and standard deviations were reported.

$$g = (X_e - X_c) / SD_c \text{-----(1)}$$

Within the formula X_E = the mean of the experimental condition whereas X_C = the mean of the control condition. For within-subjects SD_C = standard deviation for the control condition but in between-subjects design SD_{pooled} = the pooled standard deviation of the experimental and control condition, which was obtained using Equation 2. The data received from Equation 2 was then applied in Equation 3 to get a between-subjects pooled effect size.

$$S_{pooled} = \sqrt{\frac{(n_E - 1)(SD_E^2) + (n_C - 1)(SD_C^2)}{(n_E + n_C - 2)}} \text{-----(2)}$$

$$g = (X_e - X_c) / SD_{pooled} \text{----- (3)}$$

Equation 4 was used to calculate effect sizes when an F-test with one degree of freedom was presented in a between-subjects article, while Equation 5 was used in a within-subjects design.

$$g = (\sqrt{F \text{ test}}) * (((1/n_e) + (1/n_c))^{(1/2)}) \text{----- (4)}$$

$$g = (\sqrt{F \text{ test}}) / (\sqrt{n}) \text{-----(5)}$$

Equation 6 was used to convert t-test value(s) into F-test value(s), which were then used in calculating effect sizes.

$$t \text{ test} = (\sqrt{F \text{ test}}) \text{-----(6)}$$

3 RESULTS

Hedges' g , a standardized mean difference between the experimental and control conditions (Hedges & Olkin, 1985) was used as a measure of effect-size, which allows effects from different tasks and measures to be synthesized. The direction of effect-size was standardized so that positive effect-sizes represent performance improvements in the experimental group relative to the control, whereas negative effect-sizes reflect performance impairment in the experimental condition. Cohen's (1988) guidelines were used to provide an estimation of effect size, with 0.2 representing a small effect, 0.5 a medium effect and 0.8 a large effect. In the current analysis, we collapsed over common participant samples at each level of the analysis to avoid violating the assumed independence between effect-size estimates. In addition to the weighted mean effect size, two variance estimates were computed: variability due to sampling error (s_e^2) and variability of effect sizes (s_g^2). A large s_g^2 indicates there is variability among the observed effect sizes that cannot be accounted for by the sampling error and one or more variables moderating the magnitude of the effect is in question.

The 'global' (overall) effect of aperiodic noise on performance was drawn from 107 total qualifying studies and resulted in a moderate negative effect ($g = -0.53$), indicating that aperiodic noise exerts a degrading effect on performance. A secondary analysis examined performance on the different kinds of task, specifically perceptual, cognitive, psychomotor, and communication tasks. Aperiodic noise was found to have a moderate negative effect on cognitive performance ($g = -0.51$; see Table 1). The effects of noise stress on communicative performance was found to result in a moderate negative effect ($g =$

-0.45) while a small negative effect ($g = -0.36$) was found for noise stress effects on motor performance. A large positive effect ($g = 0.63$) was found when aperiodic noise was applied during perceptual performance. It must be highlighted that the results for perception, motor and communication tasks were drawn from a limited number of available studies, and so the data must be interpreted with caution. Differential effects of aperiodic noise were found when the type of dependent measure used (i.e., speed or accuracy) was analyzed. Noise was found to exert a large negative effect on performance accuracy ($g = -0.81$), whilst a moderate positive effect ($g = 0.58$) was found for performance speed (see Table 2).

A hierarchical analysis was conducted to determine whether the effects of aperiodic noise on the task types

were moderated by the type of metric used within the tasks (i.e., whether the measures were of speed or accuracy, see Table 3). While under noise stress, cognitive tasks emphasizing performance accuracy were found to suffer large negative effects ($g = -0.84$), whereas tasks emphasizing performance speed were found to be facilitated under noise (a moderate positive effect, $g = 0.58$).

Unfortunately, a low number of contributing studies for the remaining combinations of dependent measure and task type hindered our ability to obtain meaningful results.

Table 1. Moderator Analysis of Task Category

Intermittent	k	average g	s_g^2	s_e^2	s_d^2	s_e	LL 95% CI	UL CI	95%
perception	3	0.63	0.28	0.82	0	0.52	-0.4	1.65	
cognitive	95	-0.51	1.04	0.63	0.41	0.08	-0.67	-0.35	
motor	3	-0.36	0.23	0.05	0.17	13	-0.61	-0.1	
communication	7	-0.45	0.7	0.78	0	0.33	-1.11	0.2	

Table 2. Moderator Analysis of Dependent Measure

Intermittent	k	average g	s_g^2	s_e^2	s_d^2	s_e	LL 95% CI	UL CI	95%
accuracy	103	-0.81	0.67	0.62	0.06	0.08	-0.96	-0.66	
speed	17	0.58	11.77	0.28	11.5	0.13	0.33	0.83	

Table 3. Moderator Analysis of Task Category within each Dependent Measure Category

Intermittent	k	average g	s_g^2	s_e^2	s_d^2	s_e	LL 95% CI	UL CI	95%
Accuracy									
perception	2	0.58							
cognitive	93	-0.84	0.78	0.68	0.1	0.09	-1.01	-0.66	
motor	2	-0.64							
communication	7	-0.45	0.7	0.78	0	0.33	-1.11	0.2	
Speed									
perception	2	1.06							
cognitive	14	0.58	11.89	0.23	11.65	0.13	0.32	0.83	
motor	1	0.49							
communication	0								

4. DISCUSSION

The results indicate that aperiodic noise generally exerts a degrading effect on performance. Unfortunately, the majority of the studies examined only cognitive performance, limiting the ability to analyze the other task categories. This highlights the need for additional research in these areas in order to 'fill in the gaps' in knowledge. Cognitive tasks were found to degrade under noise, though differential effects were found when the type of measure used was considered. Cognitive tasks that required performance accuracy was found to degrade under noise, whilst cognitive tasks that required fast responding was facilitated under noise. These findings have important implications for Soldiers engaging in any form of task in which information processing is a key component. With the increasing use of technology in the modern army (such as wearable computers and an increasing emphasis on netcentric warfare), the disruption of Soldier cognitive performance by environmental noise constitutes a significant threat to mission success and Soldier safety.

5. CONCLUSIONS

Though the overall effect of aperiodic noise is debilitating to goal-directed performance, our analysis demonstrates that this is not always the case. Rather, there are certain combinations of task/environmental conditions under which aperiodic noise actually acts to facilitate performance (e.g., perception tasks requiring accurate responses). Aperiodic noise is a common stressor in military environments, with every Soldier exposed at some point. Accordingly, it is important to understand the differential effects of noise on the range

of task environments, thereby increasing the chances for task or mission success. Tasks vulnerable to debilitating noise effects can be recognized and steps can be taken to mitigate the threat, and tasks that are aided under noise can similarly be recognized, with a view to maximizing the potential for performance facilitation.

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